Development of the Compact Low-energy Soft X-ray CT Equipment for the Soft Material Structural Analysis

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Soft materials have a wide range of industrial applications (polymers and other organic materials). In addition, a number of biological materials are classifiable as soft materials. In the internal structure analysis of soft materials, the low-energy soft X-ray computed tomography (CT) equipment below 5keV is the most suitable tool. The existing commercial X-ray CT equipments, whose energy is in the range of 20keV-100keV, are not capable for such purposes, since the X-ray energy is too high to obtain sufficient absorption contrast. The X-ray microscopy with synchrotron radiation [1] is currently the only technique to satisfy these requirements, however, it is not commonly used in the industrial application.

A compact low-energy soft X-ray CT equipment suitable for industrial uses was developed and the proof-of-concept (POC) system has been constructed and evaluated.

Figure 1 shows a photograph of the developed low-energy X-ray CT system installation. Simple projection optics with the magnification of up to 65 was adopted for the compact and simple optical system configuration. The minimum pixel resolution of 200nm was evaluated by the silica standard particle observation.

A newly developed X-ray tube, which can generates continuum low-energy soft X-ray in the range of 2keV-5keV, is schematically shown in Fig.2. The ZrO/W thermal field emission (TFE) electron-gun is used for the high brightness source to achieve the high beam current with submicron focal spot size. The beam current of approximately 1μA at the operating voltage of 5kV was obtained.

Figure 3 shows micrographs of microcapsules made of gelatin (protein), whose thickness is 2μm, at the operating voltage of 5kV (low-energy soft X-ray) (a) and at the operating voltage of 40kV (conventional equipments) (b). The image of low-energy soft X-ray (a) can clearly observe the structure of gelatin microcapsule.

Figure 4 shows the tomographic reconstruction images of human hair fiber. The primary component of hair fiber is keratin (protein, long chains of amino acid). The hair fiber consists of three layers (medulla, cortex and cuticula). These principal layers are clearly identified by the low-energy soft X-ray CT.

[1] W. Meyer-Ilse et al: J. Microsc, Vol.201, Pt 3, March 2001, pp.395-403

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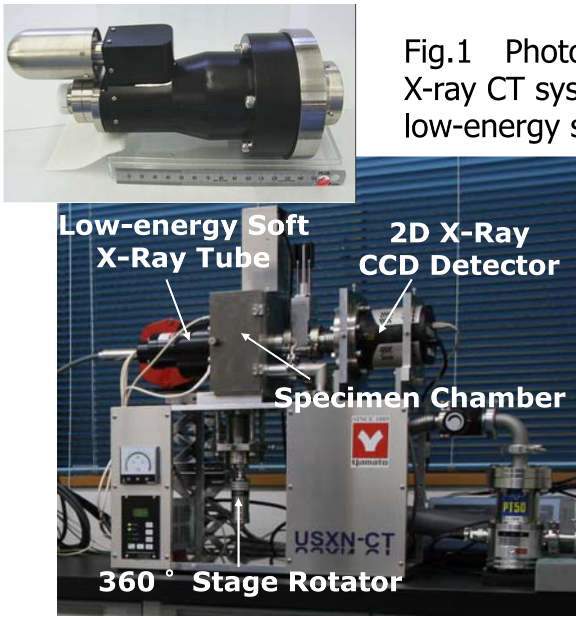

Fig.1 Photographs of the developed low-energy soft X-ray CT system installation, and the X-ray tube for the low-energy soft X-ray generation.

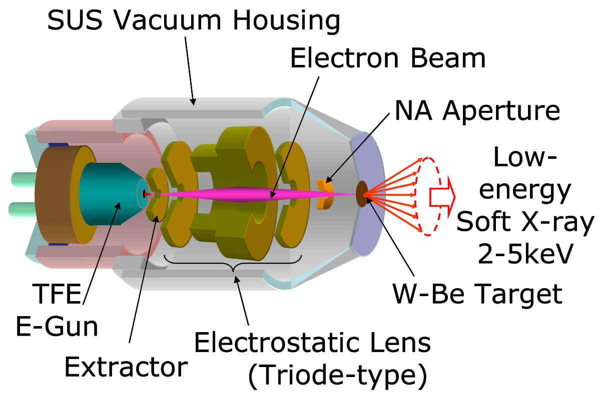

Fig.2 A schematic illustration of the low-energy soft X-ray tube.

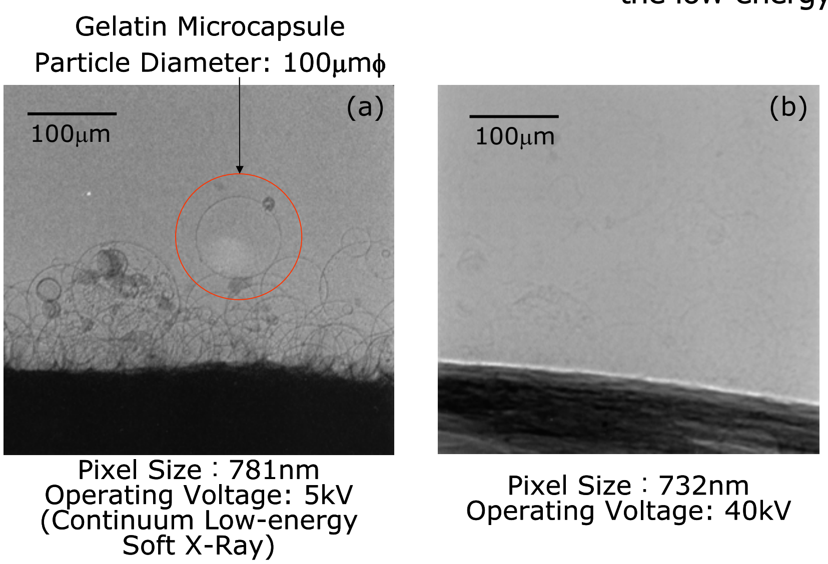

Fig.3 2D X-ray absorption contrast images of Gelatin microcapsules at the operating voltage of 5kV (a), and the operating voltage of 40kV (b).

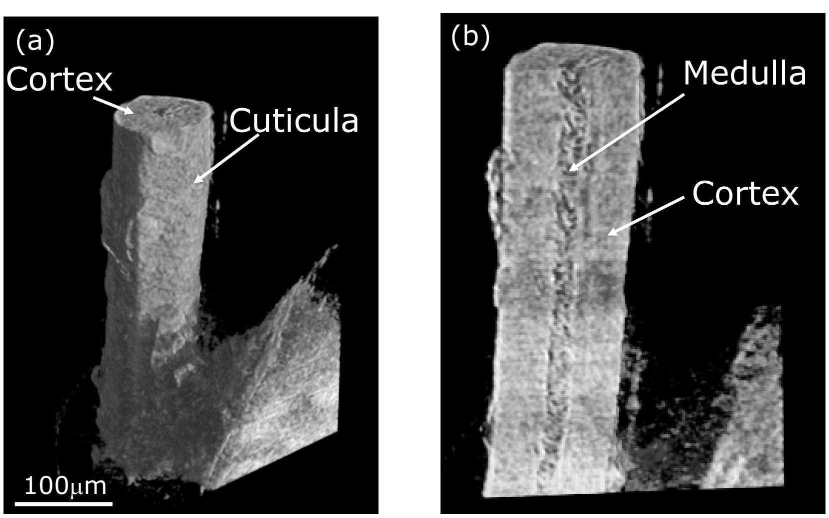

Fig.4 Tomographic reconstruction images of human hair fiber. (a) Horizontal cross-section. (b) Vertical cross-section.